Digital Protection of Power System
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Lecture 20
Digital Protection of Generators -2

Hello friends. So, in the previous lecture, we have discussed about the importance of generator protection. And we have discussed that if fault is going to persist for a longer period of time in a synchronous generator, then what are the consequences of this fault and in most of the cases the stator or rotor or the generator winding that is going to damage.

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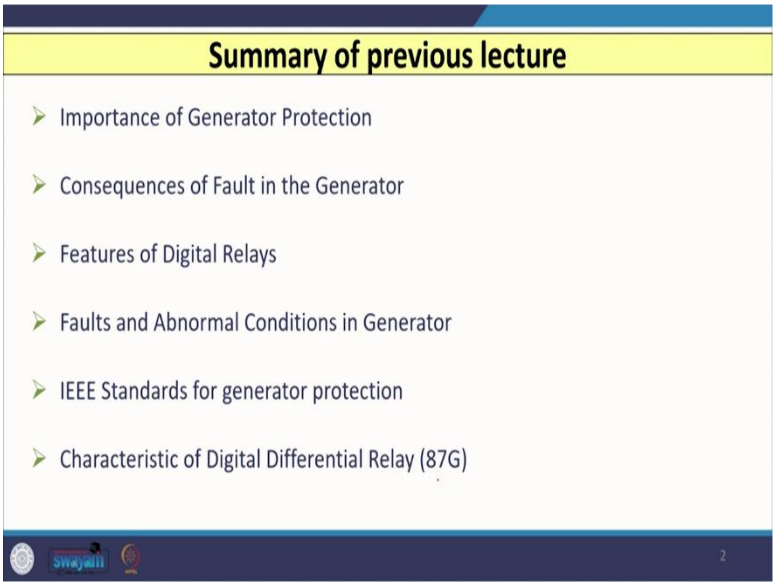

So, to avoid that nowadays digital relays are widely used by most of the utilities. And based on this we have discussed the important features of digital relays which includes many features in a single unit starting from the overcurrent to differential to earth fall to over voltage under voltage over frequency under frequency and so on.

After that we have discussed - what are the possible types of fault that is going to occur in the generator along with some abnormal conditions that is going to occur in the synchronous generator. We have also discussed three IEEE standards which are used by most of the utilities, when we design the protection scheme for a large synchronous generator.

And at the end, we started our discussion with the one of the important protection unit or protection function which is known as differential relay. And we have discussed the two slope characteristic of digital differential relay that is 87G unit. And we have also discussed the significance of pickup slope 1 slope 2 and we have discussed that in most of the cases we use the differential characteristic which is plotted based on the restraining current and the operating current.

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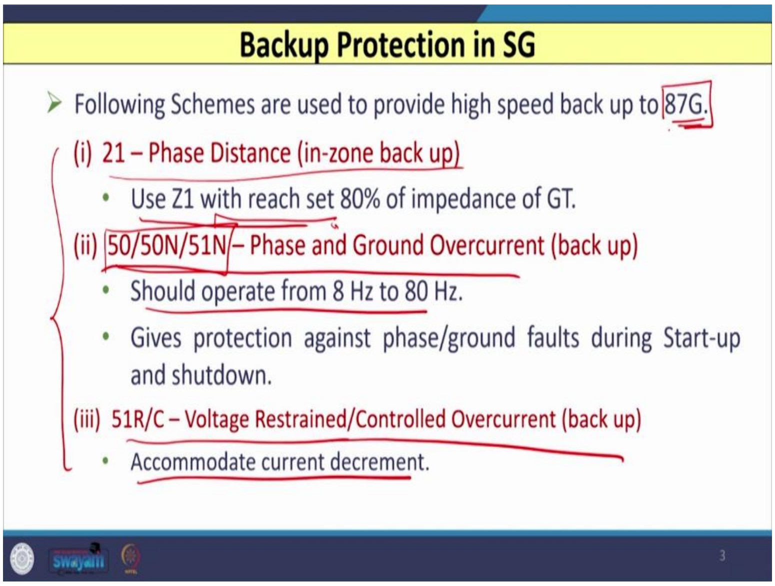

Now, in this class, let us discuss that what happens if my conventional 87G or differential relay fails to operate due to some reasons. We know that whenever faults are going to occur in the synchronous generator particularly in the stator of the generator, then the magnitude of current is very large. As I told you the normal case 210 Megawatt generator, the full load current is of the order of 10,000 ampere.

So, the magnitude of current may be 5 times or 10 times the full load current which is very large. So, to protect against the disastrous effect of this magnitude of fault current, we need a differential protection which detects the fault and operates instantaneously. However, if because of some reason this differential relay that is 87G unit fails to operate, then we also need backup protection.

So, here let us discuss what different types of backup protection are used in this synchronous generator. If our conventional differential protection that is 87G fails to operate. So, there are three types of backup protections used by most of the utilities. The first backup protection is 21 it is also known as engine backup and it is also called phase distance backup.

And in this case the offset more relay is used and the first zone reach of this offset more relay is set to 80 percent of the impedance up to the generator transformer which is nearby the generator. In some of the cases utilities are also using the relay based on overcurrent they may use the 50 or 50M which is overcurrent relay which operates instantaneously. And this is used both for phase as well as ground backup.

In this case, this relay overcurrent relay acted as a backup will operate in the frequency range of 8 Hz to 80 Hz and it also gives the protection against phase or ground faults during starting and shutdown of the generator unit. So, this is also an important feature of the backup protection used in case of the failure of the conventional 87G unit. The third type of unit used that is known as the voltage controlled overcurrent relay.

So, this type of unit is basically going to detect the increase in the magnitude of fault current and at the same time, it will also see whether the voltage is going to collapse or not. So, basically it is an overcurrent relay monitored by voltage. So, this relay is or unit is capable to measure the decrement in the current in simultaneously with the reduction in the voltage.

So, these three are the common backup protection scheme used in the synchronous generator when our conventional 87G unit fails because of some reasons.

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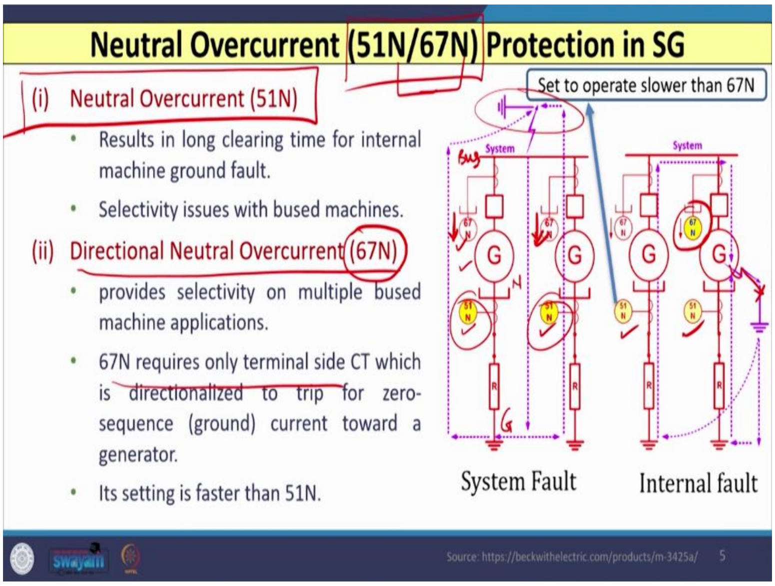

Now, the next category of protection we need for a synchronous generator that is known as the stator ground fault protection. So, for that let us consider the winding of one phase. So, this is the neutral side and this is the terminal side of the winding. And the one of the way to protect or to provide the protection in synchronous generator against ground fault in stator that is the use of over voltage relay.

So, most of the utility, earlier they used to have a relay known as over voltage relay denoted by 59G, so G indicates the ground. So, this you can see I have shown here (as shown in above slide), where the protection of this 59G or over voltage relay is provided against the ground fault in the stator and this starts from the terminal of the generator and it will available or covered up to this point. So, this will basically cover 90 to 95 percent of the winding from the terminal side.

So, this is 90 to 95 percent of the winding from the terminal side towards the neutral and this over voltage relay 59G is tuned to a fundamental frequency. However, you can see that this much of finding let us say 10 to 15 percent of the winding remains unprotected. So, 59G or over voltage based scheme is not able to provide complete protection against ground fault in the stator and we call it 100 percent protection is not possible.

So, to obtain the protection in for remaining this 10 to 15 percent of the winding turns the two types of relays are used by the utilities. The first relay you can see it is 27TN and this relay is under voltage relay based on third harmonic. So, this relay 27 is the number given to under voltage and TN is related to the third harmonic. So, this type of relay is used and this remaining 10 to 15 percent of the windings are protected by this or sometimes they may use the relay known as 59D.

So, this is also going to have the difference of the third harmonic at the terminal and the neutral ends of the winding and then you will get the protection of this remaining 10 to 15 percent of the windings, so 100 percent coverage of the winding that is fulfilled by two relays, 59G Plus 27TN or 59D. However, when I use the 59D or 27TN this type of scheme is dependent on the generator loadings as the different loadings are there on the generator, the performance of this 59D or 27TN is affected.

So, to achieve 100 percent protection against the ground fault in the stator of the generator, we need some scheme and nowadays most of the utility they use the scheme that is based on 64S and that is known as 100 percent stator winding coverage that is provided by this scheme. And this scheme is going to use the sub harmonic injection principle. So, 27TN or its performance is affected by the generator loading whereas 64S does not depend on generator loading, its performance remains unaffected.

And at the same time it will provide 100 percent protection against ground faults at any location from the terminal to the neutral. So, all the percentage of the turns of the winding that is covered. The next category of protection is known as the overcurrent protection in the neutral of the synchronous generator. And this is given by two relays one is known as 51N other is known as 67N, N is related to the neutral of the generator.

So, earlier case most of the utility they use the neutral overcurrent protection using 51N relay, however, there are certain disadvantages of this 51N relay or scheme to understand that let us consider a figure (as shown in above slide) which contains the generator and its neutral is connected through some resistor. So, this is the neutral of the generator which is connected to the ground it is further connected to the bus bar.

So, you have some bus here now, we have somewhere outside this generator winding a fault is going to occur somewhere here (as shown in above slide) then you can see that the fault current is going to flow like this or it is going to flow like this (as shown in above slide). So, as I have included 51N on both the generators there can be multiple generators also which are running in parallel in the power station.

If any fault is going to occur outside the generator protection zone, which we called as external fault then this 51N is detected such faults and both 51N will operate because this is a bidirectional relay. So, there are some selectivity issues with 51N relay or scheme or sometimes it also have a long clearing time. So, that is why this type of relays are not used nowadays.

And most of the utilities, they use directional neutral overcurrent protection scheme based on 67N. So, here I have also shown the relay (as shown in above slide), which is known as 67N the direction which I have marked is away from the bus, so, it is like this. So, if any internal fault is going to occur in the machine or generator, let us say here, I have shown one of the internal fault. So, you can see (as shown in above slide) that the current will flow like this and this relay is going to detect this fault and it will operate.

We can also use the 51N as a backup. So, in normal case, the setting of 67N is always faster than the 51N. So, this is very important advantage of the 67N that is directional neutral overcurrent scheme. Moreover, this 67N relay requires only terminal side CT which direction to trip for the 0 sequence currents towards the generator. So, this is also another added the advantage of the 67N scheme.

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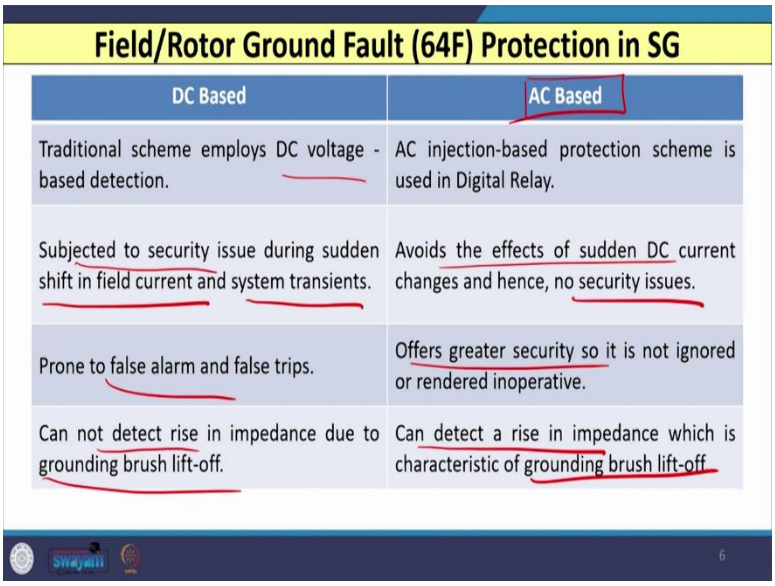

Now, the next category of fault which is possible in the generator is the rotor ground fault. Normally, whenever the ground fault is going to occur in the rotor of the synchronous generator first ground fault is not that much important and normally alarm that is issued in most of the cases. However, if second ground fault is going to occur in the rotor of the synchronous generator then tripping command must be initiated.

So, for that earlier DC voltage based detection scheme to detect the ground fault in the rotor circuit that is used by most of the utilities. However, this type of DC voltage based detection scheme which is going to detect the ground fault in the rotor of the synchronous generator, these schemes are subjected to security issues particularly when there is a sudden shift in the field current and in case of system transients.

So, this type of scheme is not used by utilities nowadays. And along with that this type of scheme DC voltage base detection scheme they may also issue false alarm and false trip in either in case of transients or sudden change in field current. And at the same time this type of scheme is not able to detect any increase in the impedance because of the grounding brush lift off. So, in this case this type of scheme may fail.

So, because of certain disadvantages of DC voltage base detection scheme, nowadays most of the utilities they will use the AC voltage based protection scheme and this is normally used by most of the digital relays. So, this type of scheme avoids the effect of sudden change in the DC current and no security issue. And at the same time it also offers greater security as it is rendered inoperative in most of the cases like to system transients and so on.

So, this type of scheme can detect increase in the impedance, particularly in case of the grounding brush lift off. So, that is why most of the utilities are using AC voltage base detection scheme for the detection of the ground fault in the synchronous generator.

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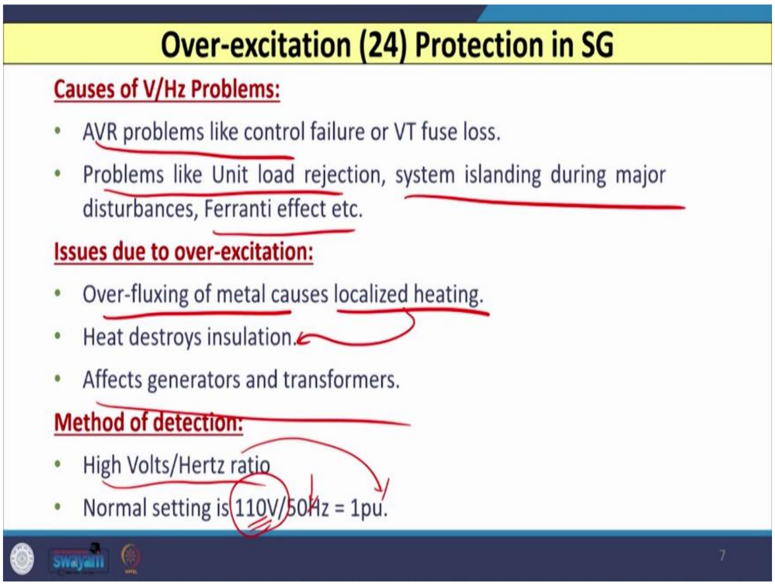

The next category of the protection is the over excitation protection in synchronous generator. So, we know that in synchronous generator because of the issues like the control failure or maybe the fuse failure of the voltage transformer or potential transformer the fluctuation of voltage is there even though we have automatic voltage regulators, but it is always there. So, we also have observed the problems like the load rejection.

Maybe system islanding during major disturbances and the Ferranti effect in most of the cases, we may have the situation which is known as over excitation condition. And there are certain issues because of the over excitation condition. So, if over excitation condition is there, then we need to detect if we do not detect then over fluxing of metal that is going to cause the localized heating.

This localized heating is going to deteriorate the insulation and it also affects the adjacent device like generator transformer GT and So, on. So, we need to detect over excitation condition. To detect this condition normally volts per hertz ratio that is to be monitored and let us say in normal condition this value of volts per hertz ratio is considered as one per unit, considering the secondary of the PT is 110 volt and fundamental frequencies 50 Hz, so ratio of these two we can assume as 1 per unit and then if this ratio exceeds some threshold value, then the over excitation condition is detected and further initiation is carried out.

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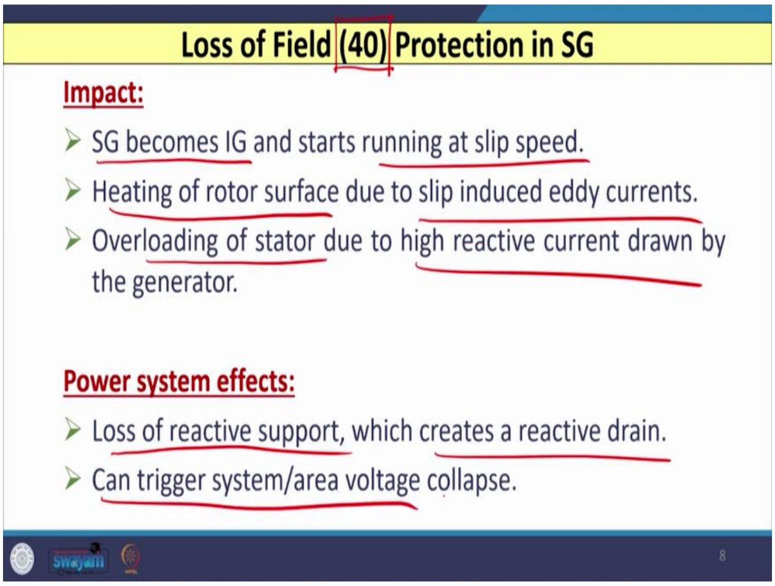
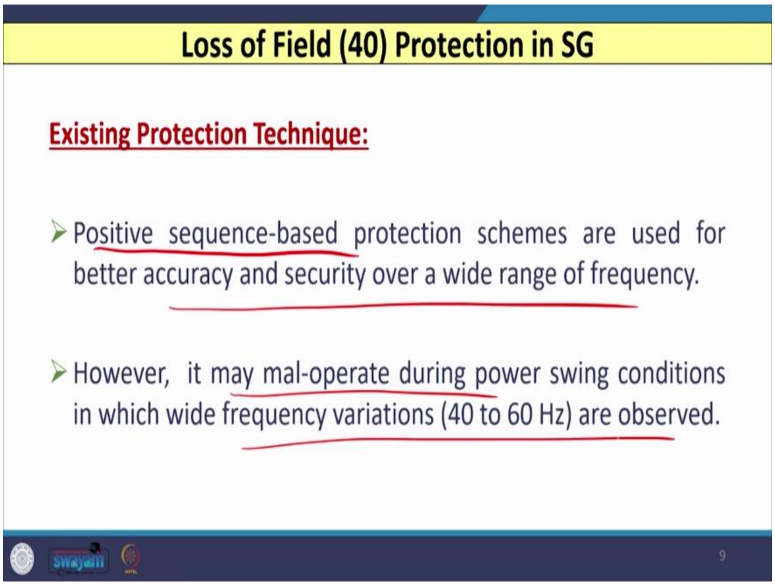


The next category of protection is known as loss of field protection in synchronous generator and number given to this that is 40. So, let us see what are the impacts of when there is a failure of field in the synchronous generator? So, when there is a failure of field in the synchronous generator synchronous generator becomes induction generator and it starts running at a slip speed.

So, because of this heating of rotor surface takes place due to slip induced eddy currents. Sometimes overloading of the stator is also there due to high reactive current drawn by the generator. If I consider the effect as far as the power system network is concerned then loss of reactive support which creates reactive drain and this may trigger the voltage collapse in certain region of the network. (Refer Slide Time: 17:52)



So, to detect to avoid this we need to detect the loss of field which is going to occur in the synchronous generator and for that the existing scheme that is going to use the concept based on positive sequence component. So, this scheme though they provide better accuracy and security for a wider range of frequency. But they may mal operate in case of power swing condition in which the frequency may vary from 40 to 60 Hz. So, this scheme may fail in that case.

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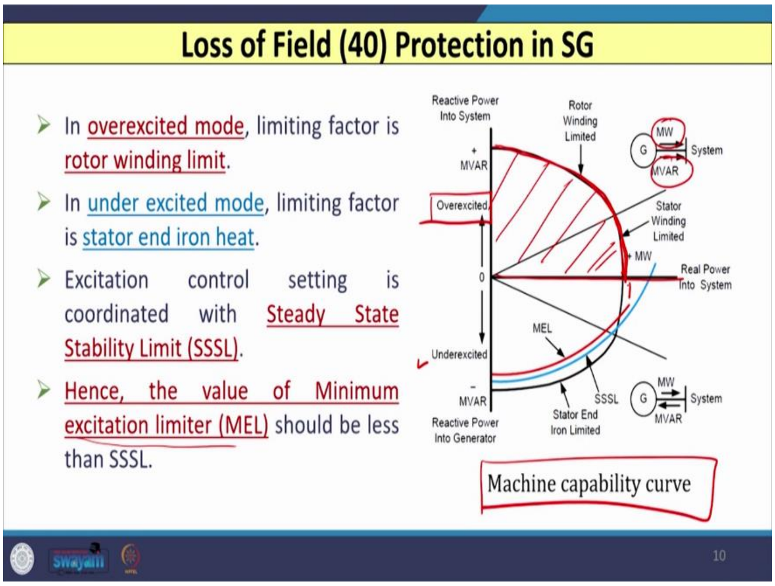

Why the scheme fails to understand that normally, the locus of loss of field is always coincide with the machine capability curve. So, you can see here (as shown in above slide) I have shown the machine capability curve in two modes when first mode is when synchronous generator is running in overexcited mode and the second when it is running in under excited mode. So, this region in overexcited mode, you can see (as shown in above slide) that both the active power and reactive power are delivered by the synchronous generator to the system.

And in that case you can see the locus is in first quadrant and this much portion is there and this limit is normally governed by the rotor winding limit. On the other hand, when such loss of field takes place, then your synchronous generator that is going to act as an induction generator. So, in that case, the lower locus you can see this will come in picture in which the generator is going to deliver the active power (as shown in above slide).

However, at the same time it is going to take the reactive power from the system. So, in this case, this limit which is in fourth quadrant that will be governed by the stator end and heat. When it is in fourth quadrant this region is more important when there is a loss of field and that needs to be detected. So, in that case when it is in fourth quadrant this limit of this machine capability curve it is when it is in under excited mode that is always coordinated with the limit which is known as steady state stability limit.

So, you can see (as shown in above slide) that in steady state stability limit, I can just show you that in case of steady state stability limit, this black curve is always coordinated with the SSSL limit and which is given by this blue curve (as shown in above slide). So, whenever you are going to have the setting of loss of field which is known as the minimum excitation limiter setting. Its line is always above this SSSL setting or line. So, that is why you can see that this red line is always above the blue line (as shown in above slide).

So that whenever loss of field is there, that will be detected by the machine before the steady state stability limit is achieved and the field breaker that needs to be tripped.

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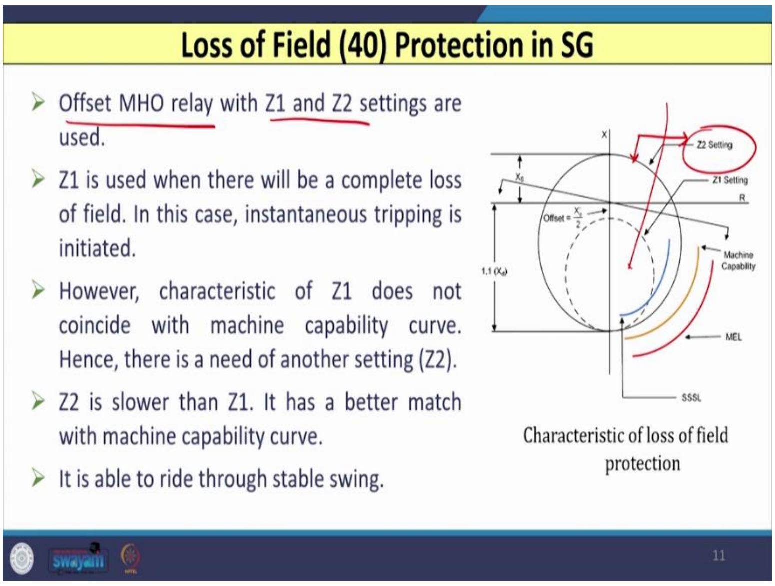

So, to achieve this normally in to detect the loss of field in synchronous generator the two types of relay settings are used. And normally they use the offset more relay with two settings Z1 and Z2. So, you can see (as shown in above slide) this dotted circle is Z1 setting and the full dark circle is the Z2 setting. So, here the Z1 setting is used when there is a complete loss of field.

So, whenever there is a complete loss of field the locus will directly come somewhere here in this Z1 and it will operate without any time delay. However, you can see (as shown in above slide) that the characteristic of this Z1 or locus of the Z1 is not coincide with the steady state stability limit of the machine. So, that is why we need another locus or circle which is known as Z2 setting.

So, Z2 setting is exactly coincide with the steady state stability limit curve and its setting is always slower than the Z1 that is why whenever some stable string is there, then it may come and it may go out of this Z2. So, Z2 is always time delayed compared to the Z1 and there should not be any mal operation in case of stable stream.

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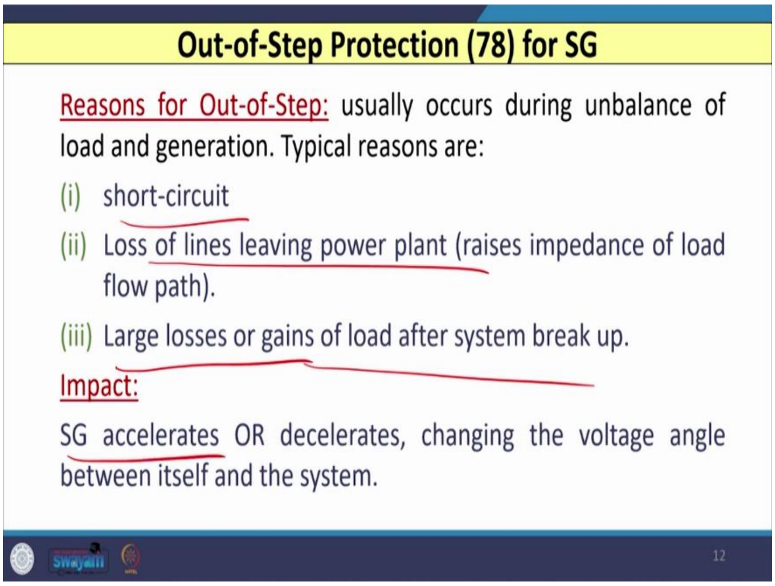

Now, the next type of protection is out of step protection in synchronous generator. So, we know that this out of step condition is going to occur during unbalance of load and generation. And the typical reasons are short circuit maybe loss of lines emanating from the power plant which is going to increase the impedance of the load flow path and large loss or gains of load after system breakup.

Because of this the unbalance is created between the load and generation and then how which is going to create the out of step condition. So, in this case, when out of step condition is there the synchronous generator either accelerate or decelerate and changing the voltage angle between the itself and the system.

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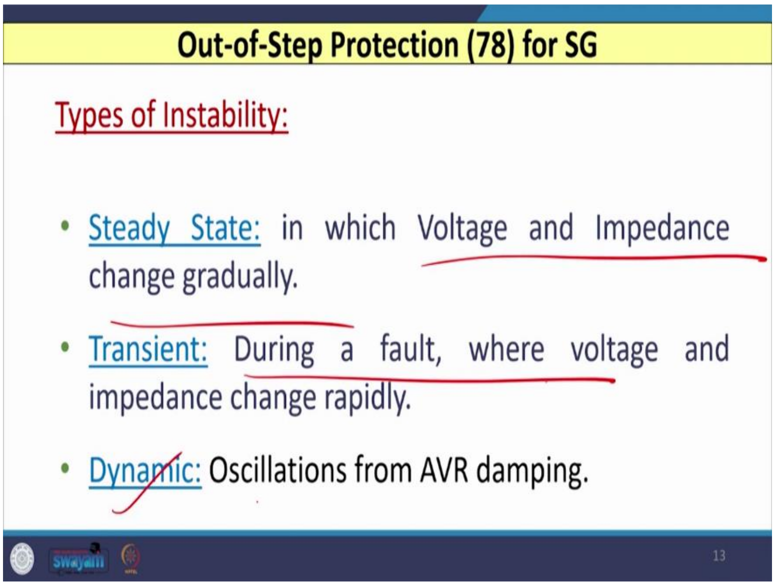

So, in this case that three types of instability are very important one is the steady state instability in which voltage and impedance change gradually. In case of transient instability, this is normally during a fault where voltage and impedances change rapidly and the dynamic instability is also there, where we will observe the oscillation from automatic voltage regulator damping.

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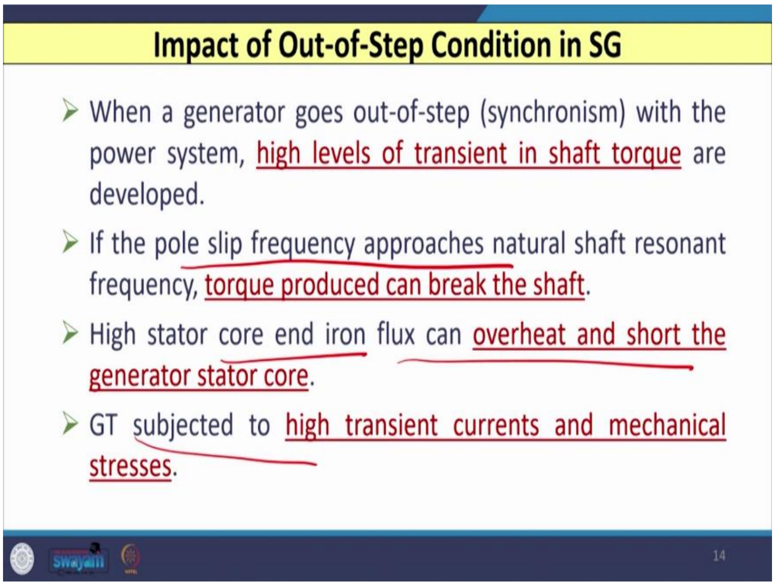

So, when such type of out of step condition exists in a generator, then high levels of transient in shaft torque are developed. If the pole slip frequency approaches the natural soft resonant frequency, then the torque produce in worst case may break the shaft. Sometimes high stator core and iron flux that can overheat and even short the generator stator core in worst case and this type of effect is also again subjected on the adjacent device that is generator transformer and this generator transformer is going to observe the mechanical stresses.

So, we need to detect out of step condition when it is going to occur on the synchronous generator. So, the thing is how we can detect this. So, to detect out of step condition in synchronous generator, single blinder scheme is used. So, the single blinder name is given because it contains two blinders means it is a pair of blinder.

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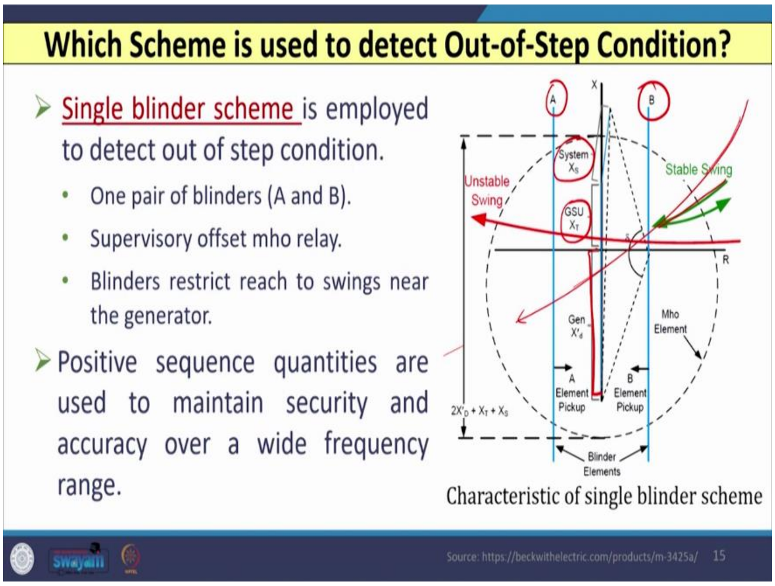

So, normally you can see here I have shown (as shown in above slide) the two vertical blue lines which is nothing but the pair of blinders and the supervisory offset, more related is used and the setting of this offset more relay is carried out in such a way that it will cover the generator XTˈvalue. It will also cover the adjacent generator transformer impedance or reactance and some system reactance is also there and then these value of this delta that is observed.

So, whenever the stable swing is observed from this side the locus of swing that will travel like this (as shown in above slide). So, when the stable swing enters the first blinder B, and when it reaches out of this blinder A and during this if this time traveled by this swing is again within the certain time limit then such type of condition is detected, if it is some other condition like fault and then this type of swing passes very rapidly.

So, before the timer times out it will pass. So, then this scheme is not going to detect such type of condition it has to detect only out of step condition.

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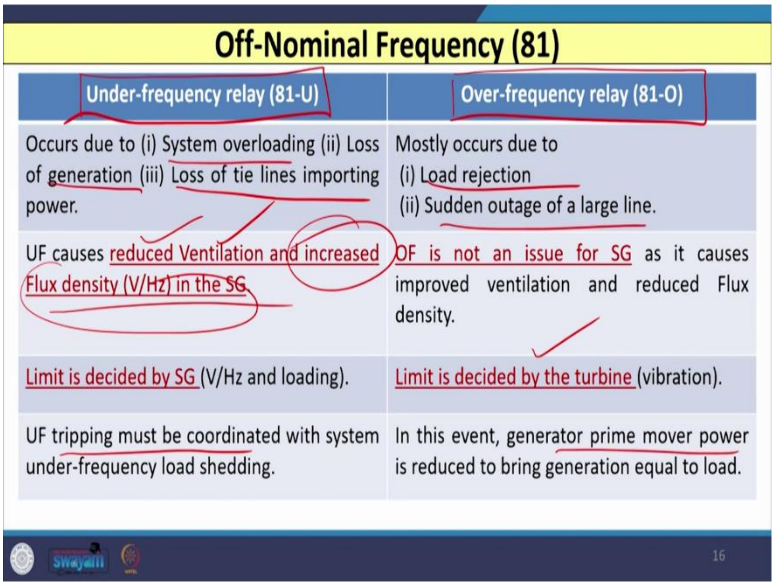

After this the next type of protection which we need to give in the synchronous generator that is off nominal frequency protection. So, in that two types of protections are there one is under frequency relays used 81-U and the second is over frequency relay is used that is 81-O. Under frequency situation occurs because of the several reasons such as the overloading maybe loss of generator or loss of unit or maybe loss of the tie line incorporating or carrying out the power.

So, whenever the under frequency situation is there, then that is going to cause the reduced ventilation and increased flux density. So, V/Hz in this synchronous generator; so this limit is normally decided by the synchronous generator itself. So, V/Hz limit is there in the synchronous generator and the loading of the synchronous generator based on these two we can define the limit of under frequency.

So, under frequency triping is normally coordinated with the load shedding scheme which we will discuss later on. On the other hand, if we consider the over frequency, then the reason for over frequency is the rejection of load or maybe sudden outage of a large line the difference is in under frequency and lower frequencies in case of under frequency the flux density that is increased whereas, in case of lower frequency it is reduced.

So, that is why the limit of under frequency is decided by synchronous generator whereas limit of the over frequency is decided by the turbine. So, in this case the generator prime mover power is reduced to bring the generator equal to the load so that this can be tackled.

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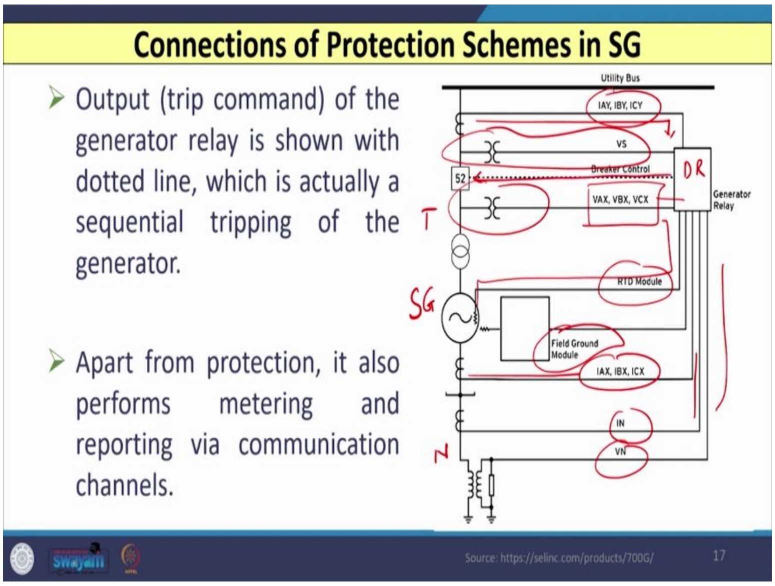

Now, using all these schemes if I summarize then let us see what different types of connections we need to give in the synchronous generator. So, here you can see (as shown in above slide) this is my synchronous generator and this is the neutral on the side of the synchronous generator and this is the terminal side of the synchronous generator and this is my digital relay for generator protection.

So, you can see (as shown in above slide) that CT secondary currents from terminal side IAY, IBY and ICY that is given again the three currents from terminal side CT secondary that is this, this is also given to the relay, from neutral side the neutral current IN and neutral voltage VN this two signals are also given to the relay. And with this you can see that the signals from the PT secondary that is also given to the relay.

So, three voltages VX VBX VCX that is given and at the same time the synchronization voltage VS input is also given to the digital relay, further if we are going to monitor the winding temperature, then the output of RTD module that is also given as an input to the digital relay. Moreover, to detect the loss of field, field ground module output is also given to the digital relay.

So, based on this any of this abnormal condition or fault is detected, then this digital relay will operate and it will give signal to the generator breaker. So, that breaker can trip along with this field breaker is also there, governor unit is also there that is also going to trip depending upon the abnormalities or fault.

Normally whenever any fault occurs or abnormal condition occur in the generator then three types of tripping that is initiated and these trippings are known as class A trip, class B trip and class C trip.

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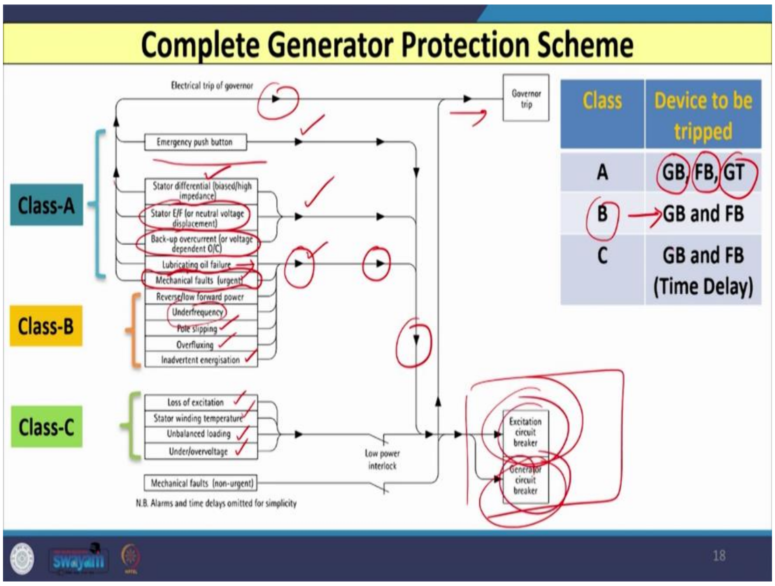

So, whenever class A trip is initiated, the conditions are when emergency push button is pressed, maybe in case of differential operation of differential relay, maybe in case of earth fault maybe in case of backup overcurrent or voltage restraint or voltage controlled relay maybe lubricating oil failure condition or maybe in case of some mechanical faults which needs to be treated urgently.

In all these cases, you can see (as shown in above slide) one of the input is given to the governor unit so that governor unit can be tripped and other cases you can see the output is available here from this three arrow and this is given to the field breaker and generator breaker. So, whenever class A trip is initiated generator breaker field breaker and governor trip all the three are initiated simultaneously without any time delay.

Certain situations are such that like reverse power or low power relay operates maybe under frequency poles slipping over fluxing or inadvertent energization of the unit or generator then in this case, you can see that this arrow that is available (as shown in above slide) here and because of this only the tripping of field breaker and generator breakers are initiated. So, you can see here (as shown in above slide) for class B trip generator breaker and field breakers are tripped.

This is also instantaneous operation without any time delay. However, in certain situation like loss of excitation stator winding temperature if it exceeds a certain limit, unbalanced loading is there or under voltage or over voltage situations are there, then in this case, the class C trip is initiated and in that case again the signal is given to the field breaker and generator breaker. So, both this will operate, but with some time delay.

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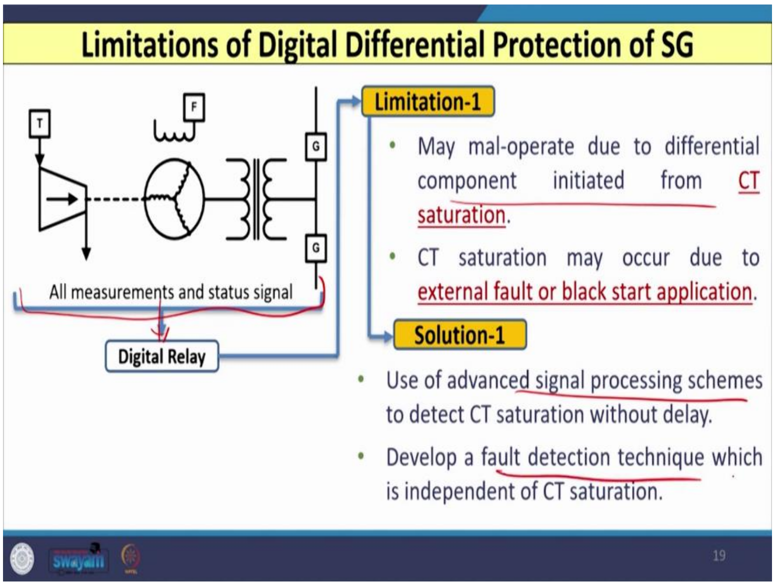

However, with this background let us see what are the limitations of digital differential protection of synchronous generator. So, you can see (as shown in above slide) that this is my generator with the prime mover and the associated generator transformer unit and we are acquiring the measurements and that is given to the digital relay. However, in most of the digital relay they may mal operate because of the CT saturation condition.

And in this case CT saturation may occur because of the external fault or maybe black start application. And in that case differential unit 87G may mal operate. So, solution of this is we have to use some advanced signal processing scheme to detect the CT saturation without any time delay or we need to develop some fault detection technique which is independent of CT saturation condition.

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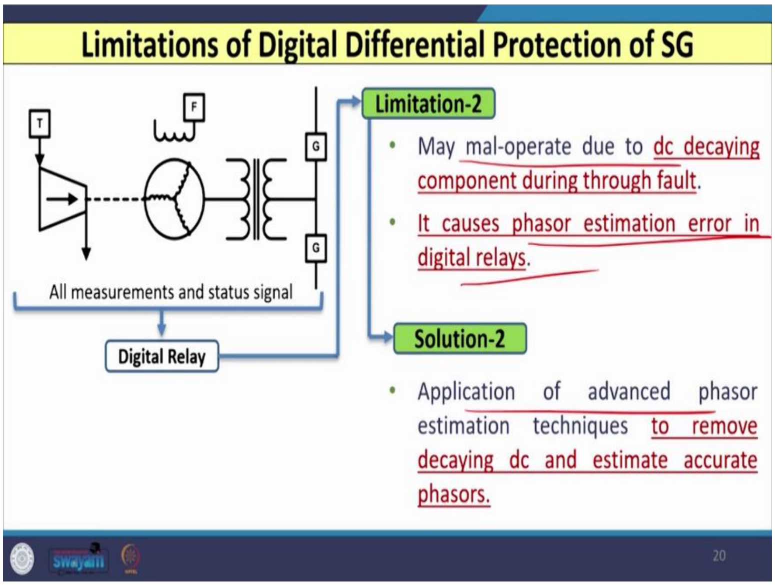

The second limitation of digital relay is this type of relay may mal operate in case of DC decaying component particularly in case of true fault or external fault. And in this case when such type of situation exists phasor estimation error is there in the digital relays.

So, the solution for this is we need to go for the advanced phasor estimation technique which can effectively remove the decaying DC component and we can effectively estimate the phasor value. So, that there should not be any error because of that the mal operation of the digital relay that can be avoided.

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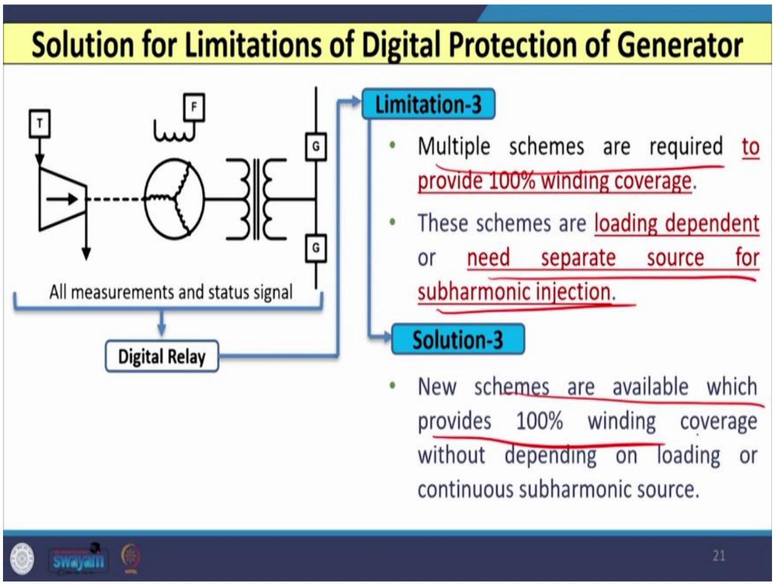

The third limitation is that multiple schemes are required to provide 100 percent finding coverage and these schemes are loading dependent and need separate source for subharmonic injection. So, nowadays these schemes are available and that is provided by most of the manufacturer which provides 100 percent winding coverage without depending on load or continuous sub harmonic source.

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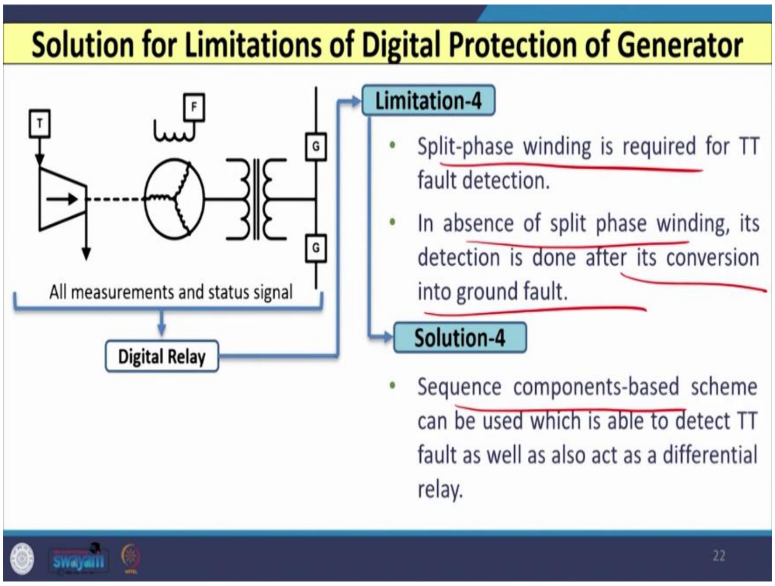

The fourth very important limitation is the split spread winding is required to detect turn to turn fault that is going to occur in any of the phase winding of the generator. So, in the absence of split phase winding, its detection is done after its conversion into the ground fault. So, the digital relay will wait for the conversion of turn to turn fault into ground fault and then the whatever unit is meant for ground fault that will operate.

So, the solution for this is we need to use sequence components base scheme which is capable to detect both the stator faults as well as turn to turn faults and which will act as a single unit. So, this can be done. So, in this lecture, we started our discussion with the different other types of faults or abnormal conditions.

And we have discussed the over frequency under frequency we have discussed the ground faults which are going to occur in stator as well as rotor we have also discussed the out of step protection and loss of field protection. And finally, we have seen - what are the problems which are going to occur in the digital relay. And we have also discussed the complete or partial solution of those problems. Thank you very much.